RESULTS FROM THE ANITA EXPERIMENT (Analysis A)

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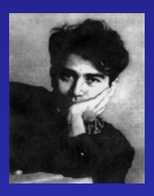
ABSTRACT

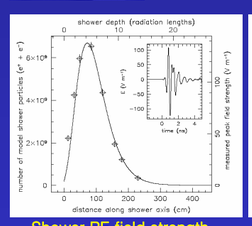
The ANITA (ANtarctic Impulsive Transient Antenna) experiment is a balloon-borne neutrino telescope which consists of an array of 32 broadband horn antennas. It successfully completed a 35 day flight over Antarctica during the 2006-2007 austral summer. The primary goal of ANITA is to search for astrophysical neutrinos with energies E > 10^{19} *eV* by detecting radio Cherenkov signals from neutrino-induced showers in the Antarctic ice. We present results from analyses of ANITA data.

ASKARYAN EFFECT

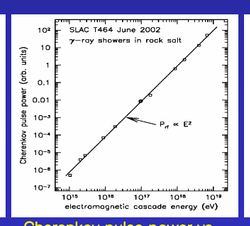


In 1962 G. Askaryan predicted that coherent radio Cherenkov radiation would result from charge asymmetry developed in an electromagnetic shower in a dielectric medium. He also noted that it could be exploited for the detection of ultra-high energy particles (E>10^{18} *eV*) interacting in large target volumes, such as the Antarctic ice sheets.

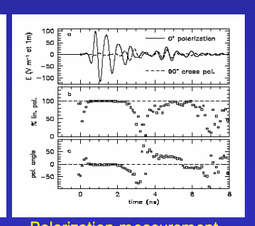
The Askaryan effect has been verified experimentally for different media including sand, rock salt and ice.


shower depth (radiation lengths)
number of model shower particles (e⁻ + e⁺)
distance along shower axis (cm)
time (ns)
measured peak field strength (V m⁻¹)

Shower RF field strength profile with typical Askaryan pulse (inset) in SLAC (2002) rock salt target experiment.



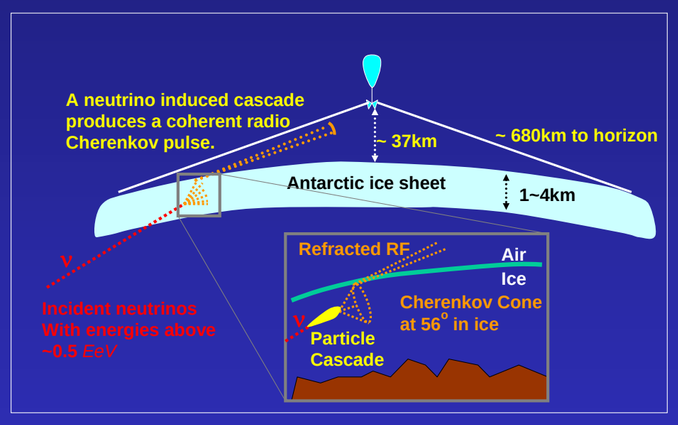
Cherenkov pulse power vs shower energy. Data are consistent with coherent radiation.



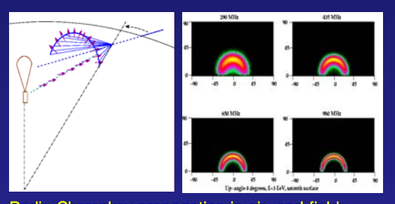
Polarization measurement confirmed 100% linearly polarized signal.

ANITA CONCEPT

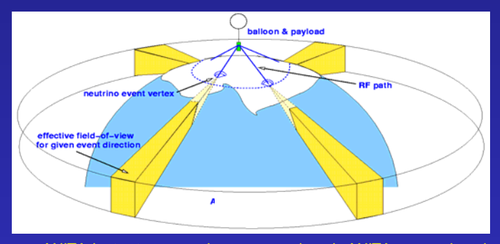
ANITA instrument is a long duration balloon (LDB) payload designed to detect radio Cherenkov signals from neutrino induced showers in Antarctic ice. ANITA has excellent sensitivity in the energy interval between 10^{19} and $5x10^{20}$ eV. With large volumes in view and excellent transparency of the Antarctic ice, ANITA provides a good opportunity for discovery.



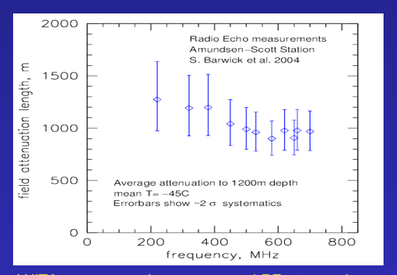
Cutaway view of Antarctic ice sheet and typical flight path of LDB. Blue circle indicates an instantaneous balloon field of view which is about one million km².



Radio Cherenkov propagation in air and field strength map for several frequencies. Neutrino direction constrained to ~<2° in elevation by earth absorption, and by ~3-5° in azimuth by polarization angle



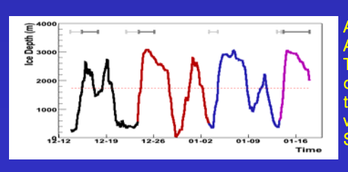
ANITA Instantaneous sky coverage band. ANITA sees a band of sky just below the visible horizon.



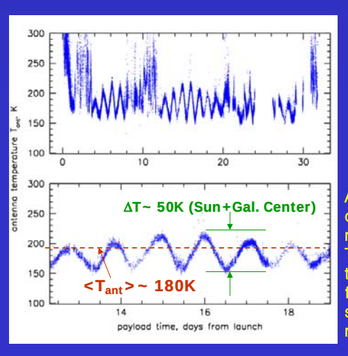
ANITA team members measured RF attenuation length at the South Pole (2004) and at Taylor Dome (2006.) The measured ~1 km of RF attenuation length is about 10 times longer than that for light.

FLIGHT (2006~2007)

ANITA launched on Dec 15, 2006 from Williams Field, Antarctica and flew for 35 days making 3.5 orbits before terminating on Jan 19, 2007. The instrument was fully recovered after it landed 360 km away from the South Pole. Although ANITA stayed much further "West" than average because of anomalous polar vortex conditions, the average depth of ice within ANITA's horizon was 1.7 km. ANITA system worked well during the flight without any lost antennas or frequency bands. ANITA was in pristine condition during ~60% of operation time, the exception being when active bases were within view, and also during the later part of flight with reduced duty cycle due to an intermittent fault.

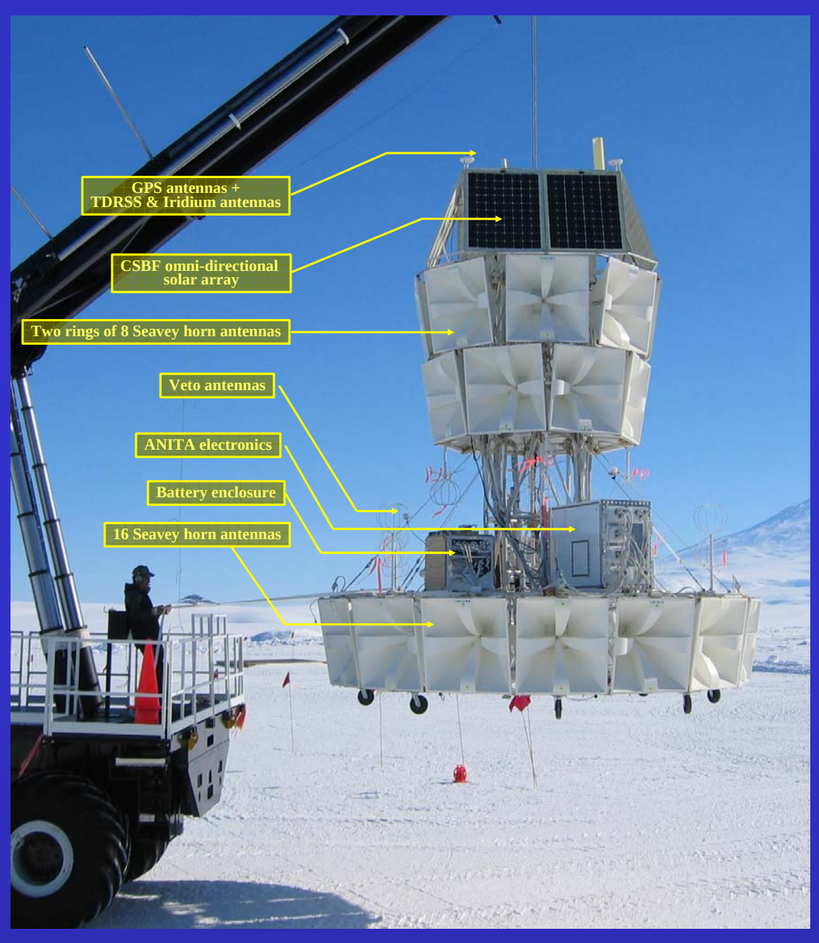


Average ice depth within ANITA's horizon vs. time. The lines above the depth plot indicate the times when ANITA was in view of McMurdo and South Pole stations.



ANITA sensitivity floor defined by thermal (kT) noise from ice + sky. Thermal noise floor seen throughout most of flight, but punctuated by station and satellite noise

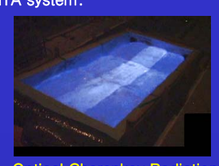
ANITA INSTRUMENTS


GPS antennas + TDRSS & Iridium antennas
CSBF omni-directional solar array
Two rings of 8 Seavey horn antennas
Veto antennas
ANITA electronics
Battery enclosure
16 Seavey horn antennas

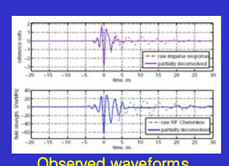
CALIBRATION AND VALIDATION

Experiment setup for SLAC beam test 2006 displayed on PRL Vol. 99

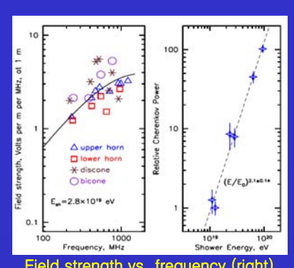
BEAM TEST: The ANITA instrument has been calibrated using Askaryan signals from an ice target with a 28.5 GeV electron beam at the Stanford Linear Accelerator Center (SLAC) in June 2006. This test was the first confirmation of the Askaryan effect with ice. All key parameters of the Askaryan effect such as frequency dependence, absolute RF power and Cherenkov width are well confirmed with ANITA system.



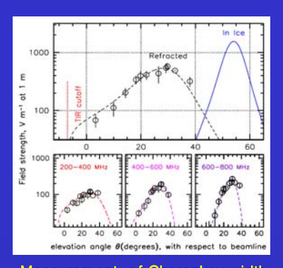
Optical Cherenkov Radiation from the ice target



Observed waveforms Askaryan pulse



Field strength vs. frequency (right) and power vs. shower energy (left)



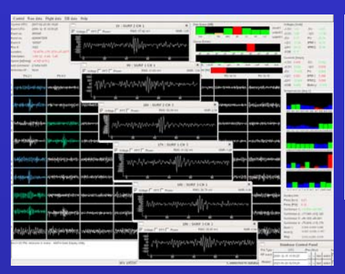
Measurement of Cherenkov width

In-flight Calibration: To verify the health of the instrument during the flight we operated ground-based pulser systems at both Williams Field at McMurdo and a field camp at Taylor Dome. Radio impulses were sent from surface horn antennas and discone antennas located in boreholes below the surface of the ice. RF trigger system, RF propagation from ice to air, and pointing ability are fully tested.

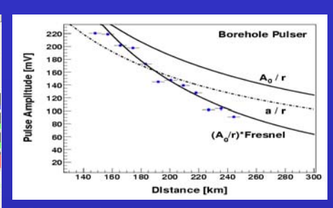
Surface horn antenna and ANITA in a test prior to flight. Borehole discone antenna is not pictured.

Taylor Dome Field Camp

Trigger pattern with a pulse for a borehole pulse. 50-100 % of trigger efficiency is achieved for 5.4-7 σ of V_{rms}

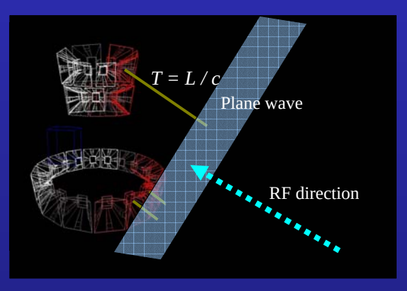


Borehole pulse waveforms with event display



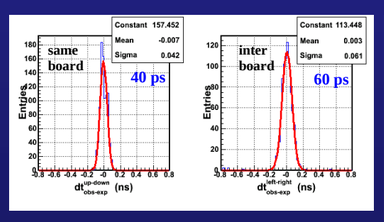
Observed borehole pulse amplitude vs. distance to ANITA. A good agreement with the expectation confirms absolute amplitude and model for Fresnel effect at ice-air boundary.

EVENT RECONSTRUCTION

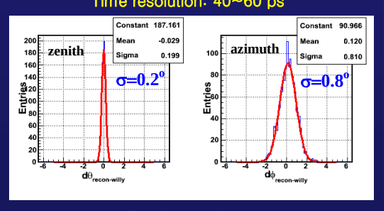


Angular reconstruction of RF signals is a crucial part in the ANITA data analysis. It provides powerful rejection of incoherent thermal noise events (which comprise ~99% of the data set), anthropogenic RF events from existing bases and field camps, and radio Cherenkov events from air showers. If ANITA observes candidate neutrino events, angular reconstruction will be crucial for energy reconstruction, providing direction information, propagation distance (for $1/R^2$ correction) and RF refraction angle on the ice-air boundary (for Fresnel correction).

A precise direction is reconstructed using arrival timing information. We obtained time resolution 40-60 ps for arrival time differences between two antennas. We performed a χ^2 fit using 5-6 channels of timing information. Achieved angular resolutions are 0.2° (zenith) and 0.8° (azimuth). The resolution in azimuth is worse than in zenith due to the shorter distances between antennas in the horizontal direction and additional timing jitter in clock synchronizations between digitization boards. Reconstruction efficiency is ~98% for S/N greater than 4.5 σ while mis-reconstruction rate is less than 0.02%.



Time resolution: 40~60 ps



Angular resolution

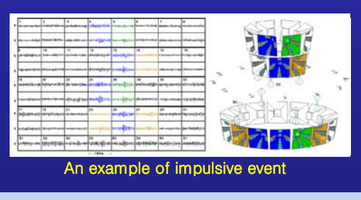
Event map with borehole pulses

PRELIMINARY DATA ANALYSIS

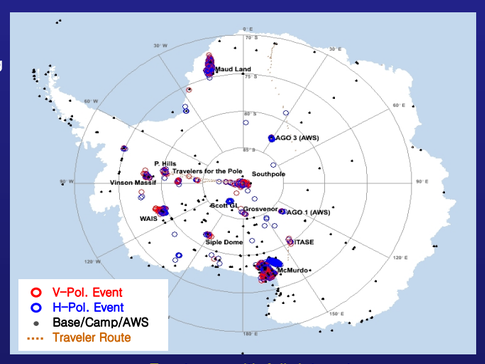
In order to avoid any biases in the data analysis, we follow blinding procedures until all analysis methods are established. We blinded 90% of data set while using remaining data sets for background studies.

NEUTRINO HUNTING

- Using 7.5 M events
- *V*>3 σ for antennas in the maximum voltage phi sector.
- Establish angular reconstruction and select good events.
- Select impulse events
- Check events against existing camps, anything that repeats.
- Test events with a likelihood function. The likelihood consists of 3 PDFs; χ^2 of angular reconstruction fit, number of cycles of time domain waveform and voltage ratio of V-pol to H-pol. The PDFs are obtained with ANITA MC simulation with the GZK (ESS model) flux distribution.



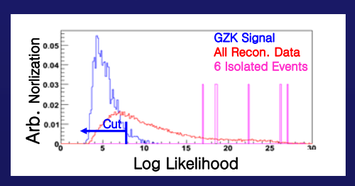
An example of impulsive event



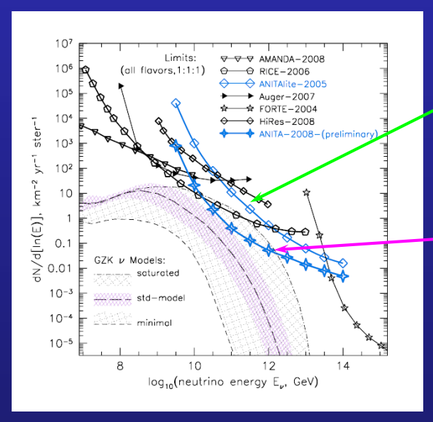
Event map with full data set.

RESULTS

- 19695 events (9600 V-pol, 10095 H-pol) are left after good reconstruction and impulsive event selections.
- Most events are associated with camps, travellers, and automatic weather stations.
- 6 H-pol events are found to be isolated.
- No events passed likelihood threshold.



SENSITIVITY



ANITA-lite (03-04 flight):

- 18 days of data, net 40% livetime
- ~50% analysis efficiency for detection
- **Z-burst UHECR model (νν annihilation →hadrons) excluded**
- **Highest Topological defect models also excluded**

ANITA-I (06-07 flight, this work)

- 35 days of data, net 51% livetime.
- ~80% analysis efficiency
- ν_e ν_μ ν_τ included
- full-mixing assumed
- +/- factor of 3 systematic uncertainty, because of a disagreement between two independent ANITA MC simulators (Further investigations would improve it).

OUTLOOK

Many analyses are ongoing for other important topics such as neutrino flavor identification, neutrino cross section measurement, air shower produced radio Cherenkov detection, and a monopole search. ANITA II is scheduled to fly in 2008. We expect a factor 4 sensitivity improvement with upgrades to the trigger, additional antennas under the lower tier, front-end electronics and DAQ.

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